Comment on "Spontaneous Inflation and the Origin of the Arrow of Time"

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Abstract

Recently, Carroll and Chen [hep-th/0410270] suggested a promising natural explanation of the thermodynamic arrow of time. However, we criticize their assertion that there exists a Cauchy hypersurface with a minimal entropy and argue that such a Cauchy hypersurface is not needed for an explanation of the arrow of time.

Recently, Carroll and Chen [1] proposed an interesting natural explanation of the thermodynamic arrow of time. Their proposal consists of two main ingredients. First, they observe that if an arbitrarily small patch of space contains an *infinite* number of the degrees of freedom, then the entropy of this patch is not bounded from above, so it is not unnatural to have a state in which the entropy is not the maximal possible one. This allows the entropy to always increase from *any* given starting point. Second, in order to understand why the process of entropy creation would create regions of spacetime resembling our observable universe, they appeal to spontaneous eternal inflation requiring a positive cosmological constant and an appropriate inflaton field.

In this comment, we have little to say regarding the second ingredient related to inflation. Instead, our comment refers to the first ingredient, which is the essential one for the understanding of the time arrow itself. Since the two opposite directions of time should, *a priori*, play equal roles, Carroll and Chen argue that for a *typical* initial condition on a given Cauchy hypersurface, the entropy increases in *both* directions from this hypersurface. Thus, they predict the existence of a turning point (or, more precisely, of a turning Cauchy hypersurface) at which the entropy attains a minimum. (Incidentally, the existence of such a turning Cauchy hypersurface was suggested also in [2], but there, such a hypersurface was considered special, rather than typical.) In this comment, we criticize the assertion of Carroll and Chen that, for a typical initial condition, the entropy increases in both directions from

the initial hypersurface. Instead, we suggest a reformulation of their proposal, so that such a turning hypersurface is not needed for an explanation of the arrow of time.

Our criticism goes as follows. According to the picture of the universe proposed in [1], the entropy increases in both time directions from the initial hypersurface. However, at *any* other Cauchy hypersurface (that does not share common points with the initial one) the entropy increases typically *only in one* direction. But this means that, among all hypersurfaces, the initial hypersurface has a *unique* property of having the time arrow in both directions. In other words, the initial hypersurface having two directions of time is *not typical at all*. Instead, *the points of a typical hypersurface have a time arrow in one direction only.*

Another way of formulating our objection is as follows. Let us consider the whole solutions of the equations of motion, rather than the initial conditions. Given the assumption that the entropy is unbounded from above, what are the properties of typical solutions defined *everywhere* in the universe? We agree with the assessment of [1] that most, if not all, of the spacetime points in the universe will have a time arrow. But is there any typicality argument that suggests that there will be a Cauchy hypersurface that represents a turning point for the *whole* universe? We do not see any such argument. Of course, in a huge eternal universe, it is not unreasonable to expect small spacetime regions where the entropy attains a *local* minimum. However, we do not see a reason why such a region should take a form of a complete Cauchy hypersurface for the whole universe.

Apparently, Carrol and Chen have introduced the notion of a Cauchy hypersurface with a minimal entropy in order to have a manifest symmetry between the two opposite directions of time. Does it mean that our criticism suggests that there is no such symmetry? Fortunately, the answer is no! According to our picture, typical points in spacetime have a time arrow in one direction only, but we cannot predict which direction is that, because all directions are, *a priori*, equally probable. However, the point is that the universe simply *must* choose some direction at (almost) every point, because otherwise it will be a rather atypical universe. In other words, the choice of the direction of a local time arrow is a matter of *spontaneous symmetry breaking*. Different regions of the universe may have different directions of the time arrow, in an analogous (although not equivalent) way as they may have different directions of the Higgs field.

In our observable part of the universe, the existence of a time arrow seems to be a rather global (not local) phenomenon. On the other hand, our typicality argument above by itself does not explain why the time arrow seems to be so uniform on such a large scale. However, here it is the spontaneous inflation discussed in [1] that may solve the problem. Owing to the inflation, an initial local time arrow will naturally become a large scale phenomenon.

At the end, let us emphasize once again that, in [1], the existence of an infinite number of the degrees of freedom in an arbitrarily small patch of space is the crucial assumption needed for the explanation of the time arrow. While this assumption is certainly problematic from the point of view of ultraviolet divergences in field theory, it is interesting to note that this assumption may also be helpful in solving the black-hole information paradox [3].

To conclude, we believe that the idea based on an infinite number of the degrees of freedom and spontaneous inflation introduced in [1] is very promising in explaining the thermodynamic time arrow. However, we also believe that our comment represents an important refinement of this idea.

Acknowledgment

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References

[1] S. M. Carroll and J. Chen, "Spontaneous Inflation and the Origin of the Arrow of Time", arXiv:hep-th/0410270.

[2] H. Nikolić, "The Origin of the Difference Between Space and Time", arXiv:gr-qc/9901045.

[3] H. Nikolić, "Black Holes Radiate but do not Evaporate", arXiv:hep-th/0402145.